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Asynchrony of spring phytoplankton response to temperature driver within a spatial heterogeneity bay of Three-Gorges Reservoir, China

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ABSTRACT

The increased air temperature is expected to have important driver on spring phytoplankton dynamics. To test whether spatial heterogeneity modifies the synchronous responses of phytoplankton to regional temperature driver, we evaluate temporal coherences for physical factors (temperature, water stability and non-algal light extinction), nutrients (nitrogen, phosphorus and silicon), and biomass and density of phytoplankton by Pearson correlation analysis and synchrony for phytoplankton community dynamics by Mantel test and nonmetric multi-dimensional scaling (NMS), during spring bloom (February 23–April 28, 2005) within Xiangxi Bay, a high spatial gradient bay of Three-Gorges Reservoir (China). The high level of temporal coherences for surface water temperature ($r = 0.946$, $p < 0.01$) and relative water column stability ($r = 0.750$, $p < 0.01$) were found between pair sites (A and B), in which the increase trends occurred with increase in regional air temperature during the study period. However, the low synchrony for phytoplankton dynamics were indeed observed between Site A and B, especially for the density of common dominant taxa (*Cyclotella* spp.: $r = 0.155$, $p = 0.388$) and community structure (Mantel test: $r = 0.351$). Moreover, the local habitat characteristics such as nutrient (nitrogen and phosphorus) and non-algal light extinction showed low levels of temporal coherence. It indicated that local community of phytoplankton varies rather independently within the single lentic bay with high spatial heterogeneity and that dispersal of algal organisms among locations cannot overwhelm out these local dynamics. Contrary to many studies, the present results argued that, in a small geographic area (i.e., a single reservoir bay of approximately 24 km length), spatial gradients also may influence spring phytoplankton response to regional temperature driver.

Introduction

Phytoplankton live at the interface between the abiotic and the biotic compartments of ecosystems, they play an important role in multiple nutrient cycles (Klausmeier et al., 2008). As one of the dominant features in the seasonal growth patterns of phytoplankton of oceans and lakes, spring phytoplankton bloom is particularly important with respect to food web dynamics of aquatic systems, so that the controlling mechanisms of spring phytoplankton succession has been received much attention (Henson et al., 2006; Ferris and Lehman, 2007; Peeters et al., 2007a; Nicklisch et al., 2008; Sommer and Lengfellner, 2008). Some studies have found that spring phytoplankton respond strongly to physical conditions such as irradiance, temperature and water stability, all of which are expected to be altered by climate change (Tirok and Gaedke, 2007). For example, Irigoien et al. (2000) commented on the relationship between North Atlantic Oscillation and spring phytoplankton bloom in the English Channel. Henson et al. (2006) studied the effect of meteorological conditions on interannual variability in timing and magnitude of spring bloom in the Irminger Basin, North Atlantic. Peeters et al. (2007b) analyzed to what extent the onset and early development of the spring phytoplankton bloom depends on seasonal changes in turbulent mixing, solar radiation and water temperature. Henson (2007) pointed out that the onset of water column stability is closely linked to the timing of the phytoplankton spring bloom.

During the last decades, aquatic systems were subject to change in climatic conditions and increase in nutrient loading, and it requires a better understanding of how phytoplankton response to multiple environmental stressors. Most previous research focused either on the effect of physical condition on phytoplankton dynamics (e.g. Iriarte and Purdie, 2004; Jasprica and Hafner, 2005; Henson et al., 2006; Miller and Harding, 2007; Peeters et al., 2007a) or on the effect of nutrient on phytoplankton biomass (e.g. Hunt and Matveev, 2005; Beamud et al., 2007; Çelik and Ongun, 2008; Kasprzak et al., 2008; Katano et al., 2008). Although

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Tirok and Gaedke (2007) investigated the individual and combined effects of three physical variables (irradiance, temperature and water stability) on algal dynamics using descriptive statistics, multiple regression models and a process-oriented dynamic simulation model, few studies has tried to reveal the relative importance of local (e.g. spatial heterogeneity) and regional (e.g. temperature increase) factors on the phytoplankton dynamics. As a simple and useful method, temporal coherence analyses were often used to explore whether the populations within a region are influenced more by intrinsic (local) or extrinsic (regional) factors, a key question in population ecology (Takahashi et al., 2008). Temporal coherence is defined as the phenomenon of synchronous fluctuations in one or more parameters among locations within a geographic region (Nakamoto et al., 1976; Magnuson et al., 1990). High level of synchrony indicated that the dynamics of population were determined by regional factors (e.g. temperature). In contrast, low level of synchrony suggested that local-scale regulators (e.g. nutrient) were most important. The study of this phenomenon is thus necessary to explain the underlying mechanisms that control spring phytoplankton bloom.

The reservoir-bay can provide a gold opportunity to gain a better understanding of the relative effect of regional climate driver and local spatial gradient on the spring phytoplankton development. A long reservoir-bay can be regarded as the canyon-shaped reservoir without dam which exhibited marked longitudinal gradients (Shao et al., 2010). For example, Ye et al. (2006, 2007) analyzed the spatial distribution of nutrient in Xiangxi Bay of Three-Gorge Reservoir (TGR, China), and found that phosphorus increase and nitrogen decrease along longitudinal gradients from the mouth to the headwater. Xu et al. (2009a) also illustrated the longitudinal gradients in inorganic suspended particles of Xiangxi Bay, one of non algal absorbing components which influence the underwater light condition for phytoplankton growth. Based on theoretical studies of temporal coherence, phytoplankton should exhibit coherent development patterns within a reservoir-bay with common climatic conditions if they are not influenced by spatial heterogeneity. Conversely, if asynchrony dynamics of phytoplankton is found, one may infer the predominance of local-scale regulators (e.g. nutrient and underwater light conditions). However, most previous studies of reservoir emphasized longitudinal gradients in biological, physical and chemical variables (e.g. Caputo et al., 2008), and few studies focused on temporal coherence of limnological variables within a single system (Lansac-Tôha et al., 2008).

Three-Gorges Reservoir (TGR), located in the mainstream of the Yangtze River (China), is one of the largest man-made lakes in the world, with capacity of $3.93 \times 10^{10}\,m^3$, water level of 175 m and surface area of 1080 km^2 (Huang et al., 2006; Xu et al., 2009a). The reservoir includes 40 large reservoir-bays (watershed area > 100 km^2) and the surface area of these bays account for 1/3 of the total surface area of TGR (Cai and Hu, 2006; Huang et al., 2006). Since the reservoir was filled to an altitude of 135 m above sea level in June 2003, algal blooms often occur in these bays (Cai and Hu, 2006). At the time, scientists and policy makers were concerned that the bays of TGR was showing symptoms of eutrophication, because no algal blooms were reported before the construction of Three-Gorge Dam. The Xiangxi River is the largest tributary of TGR in Hubei Province. After the first impoundment, the lower ca. 24 km stretch of this river became Xiangxi Bay (a representative bay of TGR), and a series of limnological observations have been taken by Xiangxi Ecosystem Station, Chinese Academy of Sciences (CAS) and China Three Gorges Project Corporation (CTGPC) (Cai and Hu, 2006). In this study, we performed temporal coherence analyses to test whether spring phytoplankton response to regional temperature driver was altered by local spatial heterogeneity, based on bidaily monitoring of pair sites on abiotic factors and phytoplankton during spring bloom in Xiangxi Bay in 2005.

Materials and methods

Field sampling

Site A for daily monitoring and Site B for bidaily monitoring were set up in Xiangxi Bay in the present study (Fig. 1). Site A and B located ca. 5 km and 18 km upstream from the mouth of the bay, with the depth of ca. 23 m and 16 m, respectively. From February 23 to April 28, 2005, 300 mL surface water samples for nutrient measurements, including nitrate nitrogen (NO3-N), phosphate phosphorus (PO4-P), and silicate silicon (SiO2-Si), and 1.5 L surface water sample for phytoplankton quantitative investigations were collected between 10:00 and 14:00 using a 5 L Van Dorn sampler. The samples for dissolved substance analyses were stored in a pre-cleaned plastic bottle, acidified *in situ* with sulfuric acid to make pH $\leq$ 2 and held on ice until laboratory measurement (Huang et al., 2000; Cai, 2007). The quantitative samples for phytoplankton identification were preserved *in situ* with standard Lugol's solution. A sedimentation method was used to concentrate 1.5 L of water samples to 30 mL of quantitative sub-samples for phytoplankton identification, and those sub-samples were fixed in 5% neutral formalin (Huang et al., 2000; Cai, 2007). An additional 300–600 mL of water was filtered through a microfilter (0.8 μm) for Chlorophyll *a* (Chl. *a*) determination, and the filter was immediately placed in a dark cooler and packed in ice until the laboratory analysis (Huang et al., 2000; Cai, 2007). *In situ*, transparency (SD) was measured with a 20 cm Secchi disc, and water temperatures (WT) of surface and bottom were recorded with a Horiba U-20 Water Quality Meters (HORIBA Advanced Techno, Japan). During the study period, the data of average daily air temperature was provided by Xingshan Weather Station, located about 18 km north from the Xiangxi Bay.

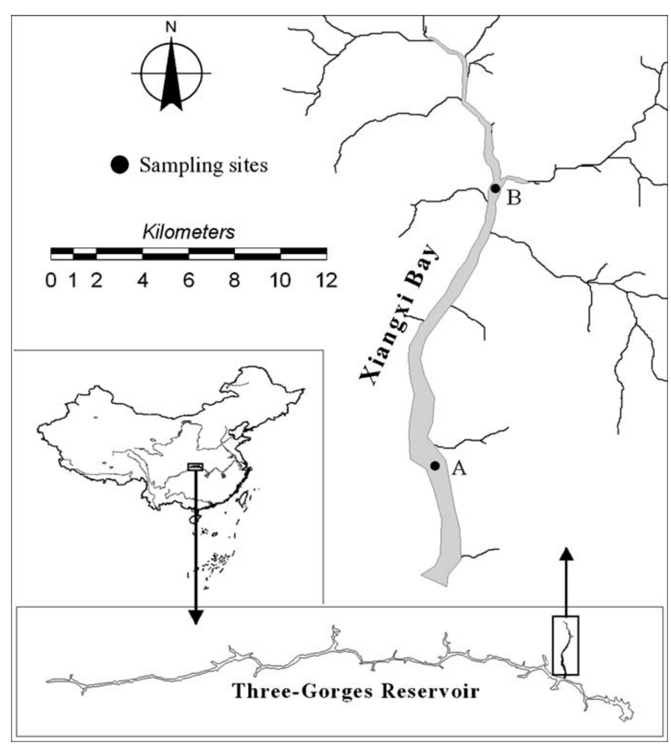

Fig. 1. The sampling sites of the study located in Xiangxi Bay, Three-Gorges Reservoir (China).